ESEARCH HIGHLIGHTS

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REVIEW OF HYGROTHERMAL MODELS FOR BUILDING ENVELOPE RETROFIT ANALYSIS

Introduction

Canada Mortgage and Housing Corporation (CMHC) supports research on the durability of building envelope assemblies. CMHC has a specific interest in assessing the impact of the addition of insulation and air/vapour barriers to existing wall assemblies in order to ensure that retrofit strategies do not adversely impact the performance of the retrofitted assemblies and that the intended improvements in system performance are achieved. CMHC is engaged in the analysis of a number of retrofit scenarios for five specific wall types used in multi-unit residential and commercial office buildings. Much of the analysis will be done with computerized hygrothermal modeling tools that will be used to characterize the change in heat, air and moisture regimes within the wall assemblies as a result of the retrofits being undertaken in different weather locations across Canada. This information will then be used to predict the likelihood of durability related problems in the retrofitted assemblies overtime. As a first step, CMHC initiated a project to review available computerized hygrothermal modeling tools that would be appropriate for assessing the performance of building envelope retrofits

This Research Highlight describes the assessment undertaken, the criteria used for the evaluation and an overview of the findings of the project.

Research Program

A research project was undertaken to review and assess commercially available computerized hygrothermal modeling tools that could be used to model heat, air and moisture conditions in 5 pre-selected wall assembly types and a number of prescribed insulation retrofit possibilities.

The wall assemblies of interest are detailed as follows:

1. Brick-veneer cladding backed up with a steel-stud wall:

This assembly incorporates an air cavity, with weepholes for drainage at its base (and is therefore drained and partially vented, and includes a capillary break). The retrofit options of interest feature different types of insulated sheathing applied to the interior and exterior of the steel-stud framing. All retrofit strategies feature a 6-mil polyethylene sheet on the inboard side of the thermal insulation to act as a vapour-diffusion retarder.

2. Brick-veneer cladding backed up with a hollow-core concrete-block wall:

This wall assembly has a brick veneer supported by a back-up masonry wall and includes an air cavity, so the wall is drained and partially vented. The retrofit options feature different types of insulation applied to the interior and exterior of the concrete-block wall. In one case, an elastomeric coating is applied to the outboard surface of the concrete-block wall to act as an air barrier and water-resistant surface.

3. Pre-cast concrete panels with interior insulation:

This assembly consists of pre-cast panels with a steel-stud furring layer covered with interior drywall finish. All retrofit assemblies feature a 6-mil polyethylene sheet on the inboard side of the thermal insulation to act as a diffusion retarder.

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4. Stone-veneer cladding backed up with a solid concrete-block wall:

The stone cladding is mounted onto the concrete wall in such a way as to incorporate an air cavity, so the wall is drained and partially vented, with a capillary break. Retrofit options feature different types of insulated sheathing applied to the interior and exterior of the concrete-block wall. An elastomeric membrane is proposed for one of the retrofits.

5. Sandstone cladding backed up with a structural (600 mm) brick wall:

The interior of this assembly is finished with plaster over terra-cotta tile. This represents a heritage construction assembly in an institutional building (e.g., government edifice or museum). Retrofit options feature different types of insulation applied to the interior, and finished with drywall.

A literature and Internet search was undertaken to identify existing computerized hygrothermal modeling tools that may be suitable for the future modeling study. The next part of the project involved the development of a list of screening criteria that could be used to evaluate the tools to determine which might be suitable for modeling the selected walls and retrofits. The criteria developed are listed as follows:

1. Commercially availability: The tools must be in the public domain or readily available at cost. Tools that are for internal use at a given research facility or university would not be considered appropriate for further review. "Availability" in this context, also implies "available at a reasonable price";
2. Suitability of the tools for the wall types and retrofits under consideration (as previously described);
3. The degree to which the tools have fully transparent algorithms, and are of reasonably recent vintage, and can operate on a personal computer (preferably on a Microsoft Windows© platform);
4. Documentation. This should include a description of the algorithms, program limitations, and instructions for proper program usage;
5. User-friendliness of the tools to a reasonably informed architect or engineer;
6. Technical support and training availability;
7. Accurate and current material property data. All computerized Hygrothermal modeling tools use measured hygrothermal property data for various materials as input. The tool is no more accurate than its input, so a key element of the tools evaluation involves the accuracy of the data included in the tool, and the ease with which a user can include data for additional materials, or updated data for the materials in the tool.

Findings

Fourty-five computerized hygrothermal modeling tools were identified and are listed in Table 1. However, it was quickly discovered that most of them do not meet the first criterion, as they are not readily available to the public outside of the organization where they were developed. In fact, only the following eight computerized hygrothermal modeling tools reviewed meet this criterion.

1. DELPHIN4 is a two-dimensional model for transport of heat, air, moisture and salt in porous materials. It arose from the old DIM program developed at the Technical University of Dresden, Germany. A 30-day trial program can be downloaded at no cost.
2. EMPTIED is a one-dimensional model for heat and moisture transport, with some considerations for air leakage included. It can be obtained at no cost by request from Canada Mortgage and Housing Corporation.
3. GLASTA is a one-dimensional model for heat and moisture transport. It is based on the Glaser method, but includes a model for capillary distribution within the layers of the assembly, and may be suitable for assessing drying potential. It is available from a Belgian company called Physibel Building Physics Software.
4. MATCH is a one-dimensional model for heat and moisture transport. Dr. Carsten Rode developed it as a DOS program at the Technical University of Denmark. The DOS version can be obtained from Bygge-og Miljoteknik, a Danish insulation supplier. A Windows© version is available from Rockwool A/S, but only in Danish. The distributor reports that an English-language version of the MS-Windows© program is now available but the program was not available in time for this review.
5. MOIST is a one-dimensional model for heat and moisture transport. It was developed at the National Institute for Standards and Testing in the United States, and can be downloaded free of charge from their Internet site. It models moisture transfer by diffusion and capillary flow, and air transfer by including cavities that can be linked to indoor and outdoor air.
6. 1D-HAM is a one-dimensional model for coupled heat, air and moisture transport in a multi-layered porous wall. The program uses a finite-difference solution. The moisture-transfer model accounts for diffusion

and convection in vapor phase, but not liquid water transport. Heat transfer occurs by conduction, convection and latent-heat effects.

7. UMIDUS is a model for coupled heat and moisture transfer within porous media. Diffusion and capillary regimes are modeled, so moisture transport occurs in the vapor and liquid phases. The model can be downloaded at no cost, but only Brazilian climatic data are included.
8. WUFI is designed to calculate one-dimensional coupled heat and moisture transport. Heat transfer occurs by conduction, enthalpy flow (including phase change), short-wave solar radiation and long-wave radiative cooling (at night). Convective heat and mass transfer is not modeled. Vapour-phase transport is by vapour diffusion and solution diffusion, and liquid-phase water transport is by capillary and surface diffusion.

Of the aforementioned models, four were considered to be inappropriate for the wall types of interest (i.e., they do not meet the second criterion). Of the four remaining models, one of these was later found to be inappropriate for the future modeling research project, as the weather data for North American cities are not available and cannot be generated.

The remaining three candidate models are MATCH (from Denmark), MOIST (from the United States), and WUFI (from Germany). Each of these programs has specific strengths, but MOIST does not appear to be undergoing any further development, and technical support is no longer provided.

The MATCH version available for review appears to adequately model all aspects of hygrothermal behaviour of interest to the current research project. The newer version may provide additional features of interest, but the main drawback to the existing version is the lack of pertinent weather data. It is possible, however, to generate MATCH weather data for any location of interest from text-based weather data files. It was recommended that the research could continue with at least a preliminary round of simulation work using the existing version of MATCH. If the research team that will be undertaking the subsequent modeling project finds this program adequate, it may be appropriate to obtain the newer version of the program, which operates on the MS-Windows© platform.

The WUFI program also appears to be adequate for the future modeling research project. Although some aspects of the program could not be reviewed (due to limitations of the demonstration versions), WUFI has a simple and effective user interface, appears to model most of the heat- and moisture-transfer mechanisms of interest, and is familiar to most researchers.

Thus, either MATCH or WUFI is recommended for the next phase of this research, some additional work is required to obtain material property data, for some materials that are to be used in the research project but are not included in the material databases for the software. These materials include exterior-grade drywall, elastomeric membrane, hollow-core concrete block and terra-cotta clay tile. As noted above, MATCH weather data files should also be generated, if suitable data are not included with the Windows© version.

Implications for the Housing Industry

Although this project was undertaken in support of a larger research initiative to model insulation retrofits for specific wall assemblies, the work raised many other issues of broader interest to the housing industry. For example, although many computerized hygrothermal simulation models are available to perform building envelope performance analysis, few models are readily available to, or useable by, the consulting engineering or architecture communities in support of their design work. The project also highlights the need to be prudent in the selection and use of hygrothermal modeling tools for building envelope analysis as not all models are appropriate for all envelope types or geographic locations. All such models can generate results but how meaningful the results are will be dependent on the information input, the algorithms used to predict the resultant heat, air and moisture regimes, availability of accurate materials properties and weather data and the ability of the user to interpret the results.

Table 1: Hygrothermal Models Evaluated

Program	Model Type	Originating Agency	Agency address/Internet site
WAND	1D Heat/Moisture	Catholic University of Leuven, Belgium	http://www.kuleuven.ac.be/english/
KONVEK	3D Heat/Air/Moisture		
NATKON	2D Heat/Air		
HYGRAN24	1D Heat/Air/Moisture		
HAM	1D Heat/Air/Moisture		
HMSOLVER	2D Heat/Moisture		
GLASTA	1D Heat/Moisture	Physibel, Maldegem, Belgium	http://www.physibel.be/prodserv.html
HAMPI	1D Heat/Moisture	University of Saskatchewan, Canada	http://www.engr.usask.ca/
WALLDRY	1D Heat/Air/Moisture	Canada Mortgage and Housing Corporation, Canada	http://www.cmhc.ca or http://www.cmhc-schl.gc.ca/publications/en/rh-pr/tech/1999-123e.html
WALLFEM	1D Heat/Air/Moisture		
EMPTIED	1D Heat/Air/Moisture		
LATENITE	2D Heat/Moisture	National Research Council Canada	http://irc.nrc-cnrc.gc.ca/irccontents.html
MATCH	1D Heat/Moisture	TU Thermal Insulation Laboratory and Bygge-og Miljoteknik, Denmark	http://www.byg.dtu.dk/ or www.match-box.dk
TRATMO2	2D Heat/Air/Moisture	VTT (Technical Research Centre) of Finland	http://www.vtt.fi/indexe.htm
TCCC2D	2D Heat/Air/Moisture		
LTMB	1D Heat/Moisture	INSA (National Institute of Applied Science), Lyon, France	http://www.insa-lyon.fr/
CHEoH	2D Heat/Moisture	IMF(Institute of Fluid Mechanics), Toulouse, France	http://www.imft.fr/
TONY	2D Heat/Moisture		
V30	1D Heat/Moisture	CSTB (Centre for Building Science and Technology), France	http://www.cstb.fr/
V320	2D Heat/Moisture		
WFTK	1D Heat/Moisture	Fraunhofer Institute for Building Physics (IBP), Holzkirchen, Germany	http://www.hoki.ibp.fhg.de/
WUFI-Z	2D Heat/Moisture		
JOKE	1D Heat/Moisture	FH (University of Applied Science) at Lausitz, Germany	http://www.fh-lausitz.de/
COND	1D Heat/Moisture	TU-Dresden/FH - Lausitz	http://www.tu-dresden.de/homepagejb.htm
DIM 2.5	2D Heat/Air/Moisture	TU (Technical University) of Dresden, Germany	
DELPHIN4	2DHeat/Air/ Moisture/Salt		
HYGTHERAN	1D Heat/Moisture	NBRI Israel	http://www.technion.ac.il/~nbri/
HYGRO	1D Heat/Moisture	TNO Building and Construction Research, Delft, Netherlands	http://www.bouw.tno.nl/homepage.html
WISH-3D	3D Heat/Air		
HORSTEN	2D Heat/Air/Moisture		
P1200A	1D Heat/Moisture	SP (Swedish National Testing and Research Institute), Borås, Sweden	http://www.sp.se/eng/default.htm
VADAU	2D Heat/Moisture	Chalmers Technical University, Gothenburg, Sweden and University of Lund, Sweden and Blocon operating as buildingphysics.com in Lund, Sweden & Reading, MA USA	http://www.chalmers.se/Home-E.html or http://www.buildingphysics.com/1d-ham.htm or http://www.byfy.lth.se/Berakningsgruppen/Berakn.htm
1D-HAM	1D Heat/Air/Moisture		
AHCONP, ANHCONP	2D Heat/Air		
JAM1	1D Moisture		
JAM2	2D Moisture		
FUNKT 74:6	1D Heat /Moisture	Gullfiber AB (now Saint-Gobain Isover), Billesholm, Sweden	http://www.gullfiber.se/
NEV 3	1D Heat/Moisture	Slovak Academy of Sciences, Bratislava, Slovakia	http://www.ustarch.sav.sk/Dpt/Phys/Therm/therm.html
BRECON 2	1D Heat/Moisture	Building Research Establishment, East Kilbride, Scotland	http://www.bre.co.uk/
MOIST	1D Heat/Moisture	National Institute for Standards and Testing, Gaithersburg, MD USA	http://www.bfrl.nist.gov/info/software.html
FSEC	3D Heat/Air/Moisture/ Contaminants	Florida Solar Energy Centre, Cocoa, FL USA	http://www.fsec.ucf.edu/
UMIDUS	1D Heat/Moisture	Pontifical Catholic University of Parana, Curitiba, Brazil	http://www.pucpr.br/pesquisa/lst/
WUFI/ORNL	1D Heat/Moisture	Fraunhofer IBP/Oak Ridge National Laboratory, Oak Ridge TN, USA	http://www.ornl.gov/btc/moisture
MOISTURE-EXPERT	2D Heat/Moisture	Oak Ridge National Laboratory, Oak Ridge TN, USA	http://www.ornl.gov/btc

Notes: [a]Sources: Hens (1996), Straube and Burnett (2000), Crowther et al. (2000), Internet search

Project Manager: Duncan Hill

Research Report: *Review of Hygrothermal Models for Building Envelope Retrofit Analysis*

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Housing Research at CMHC

Under Part IX of the *National Housing Act*, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research.

This fact sheet is one of a series intended to inform you of the nature and scope of CMHC's research.

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